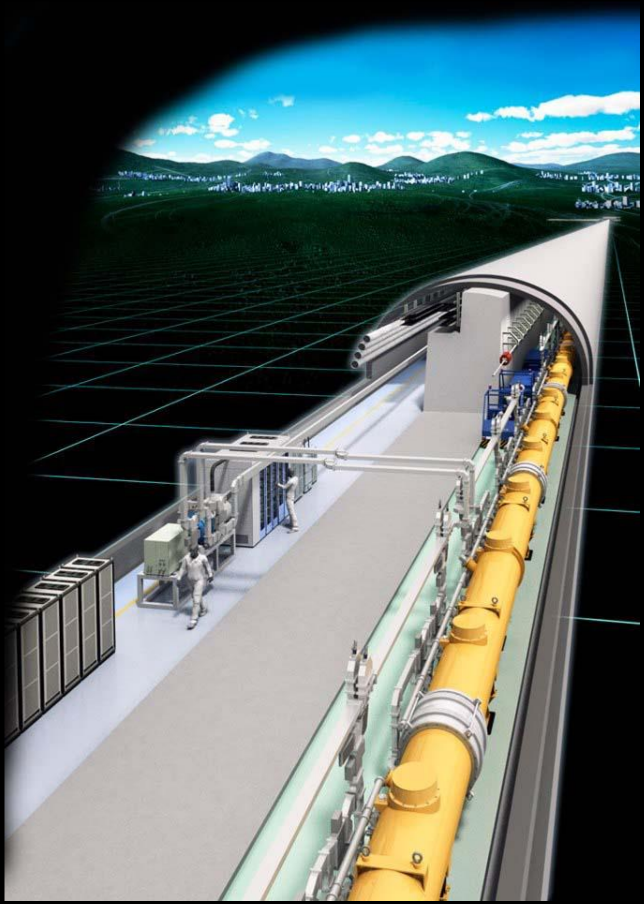
ILC Physics and Detectors
(and some reports on situation in Japan)

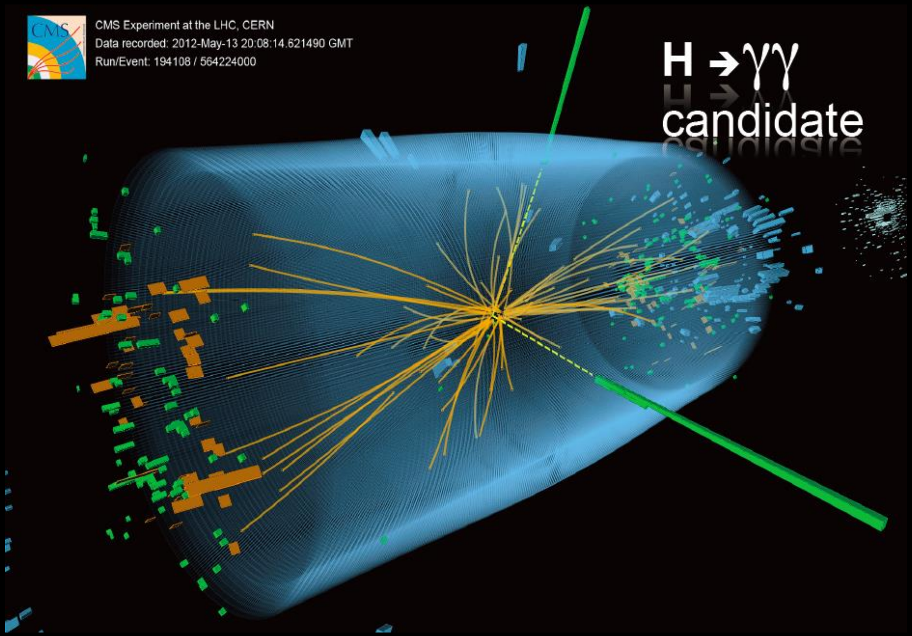


Hitoshi Yamamoto
Tohoku University

Lepton Photon Conference
June 25, 2013, San Francisco

ILC Physics

Discovery of Higgs-like particle

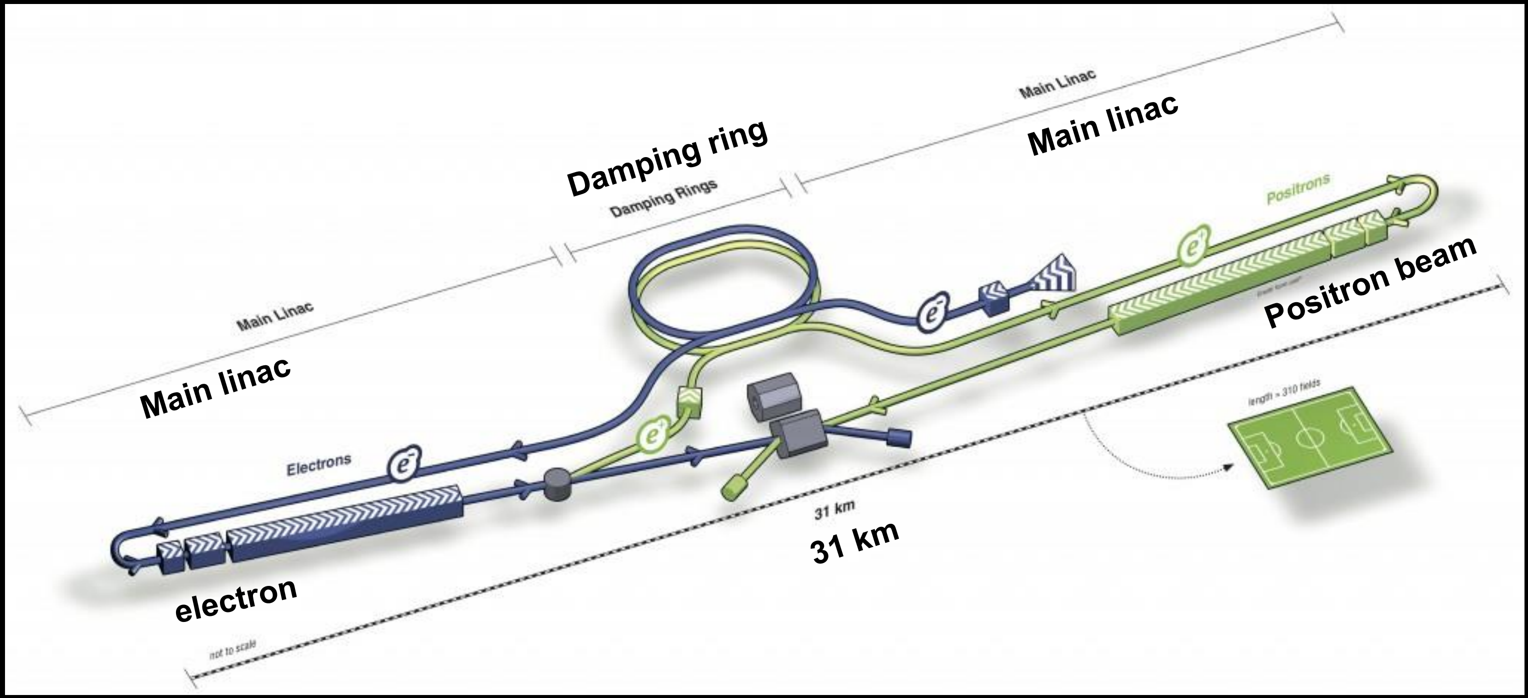


- The fine-tuning problem of the SM became real. (unless 'multiverse')
- The problem of missing dark matter in the SM became accute
- and more …
- : Compelling reasons for the next step.

A new era of particle physics has begun!

The ILC is designed to lead the new era.

ILC (International Linear Collider)



- 500 GeV CM with 31 km → upgrade later to ~ 1TeV CM with 50 km
- Luminosity 1.8 x 10^{34} /cm^{2}s (@500 GeV CM)

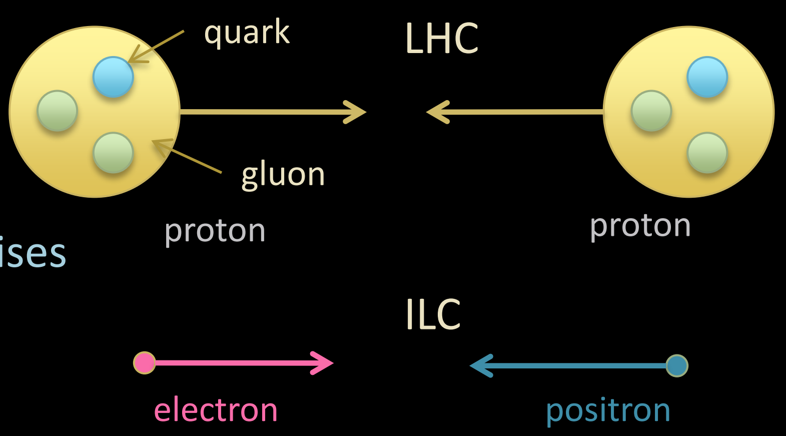
ILC features : cleanliness

- Collision of two elementary particles
  - proton + proton at LHC
    - Proton = 3 quarks + gluons
  - electron + positron at ILC

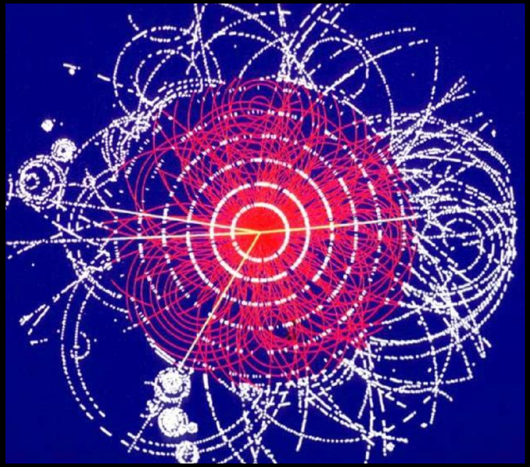
→ Signal is clearly seen without much noises

→ Trigger-less data taking

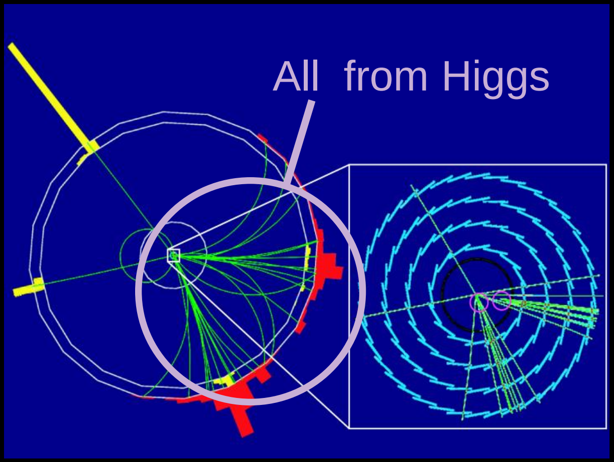
→ Theoretically clean
(less theoretical uncertainties)



LHC



ILC



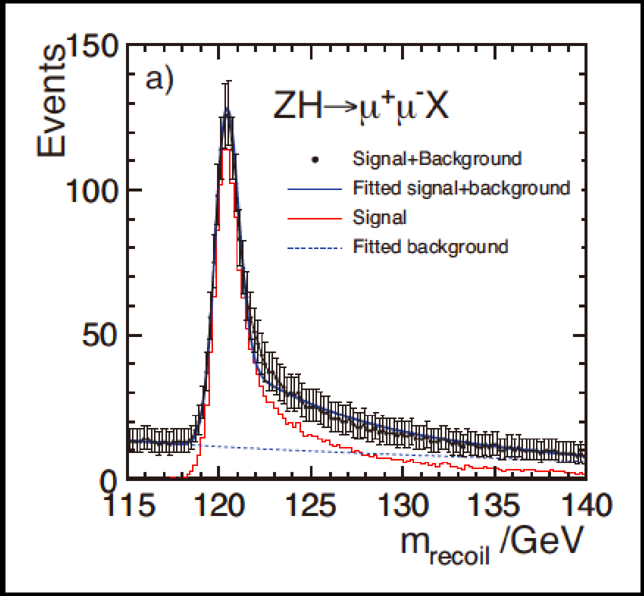
ILC features : control

- Initial state of electron-positron interaction :
  - Energy-momentum 4-vector is specified
  - Electron polarization (80%~90%) is specified
    - Positron polarization (60%) is optional (30% comes for free)

Energy-momentum 4-vector

→ e.g. recoil mass analysis: tagged Higgs

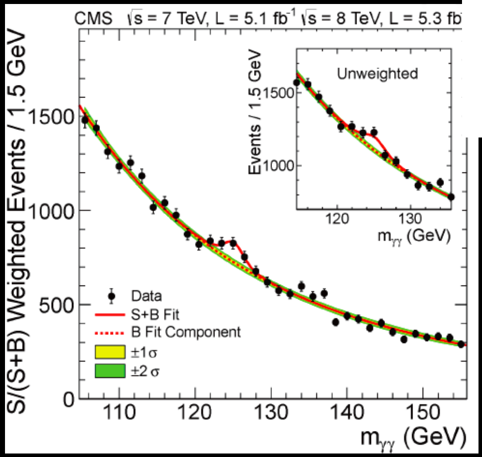
Higgs to ALL (including invisible final state)

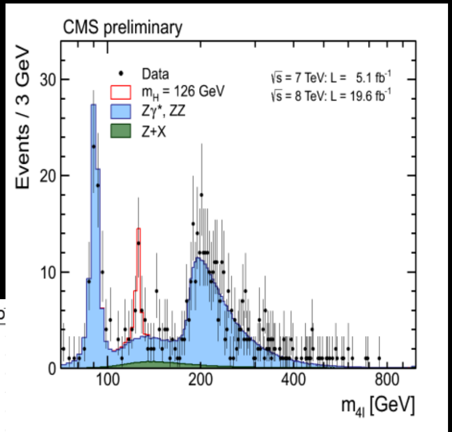


ILC

LHC

H→γγ



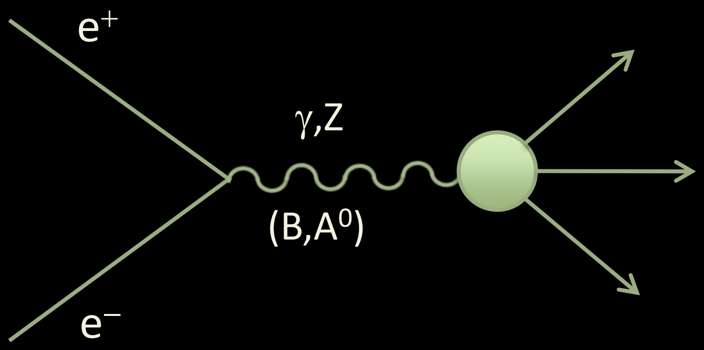


H→ZZ

Electron polarization

Specify the intermediate state

- Right-handed e- turns off A^0
  - Information on the gauge structure of the final state



Increase rates

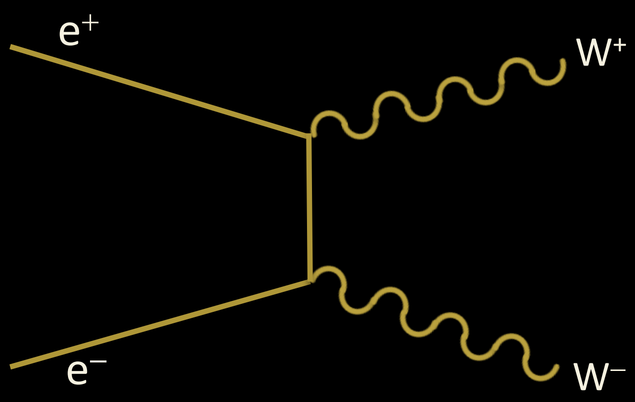
- e.g. $P^- / P^+ = -0.8/0.3$:

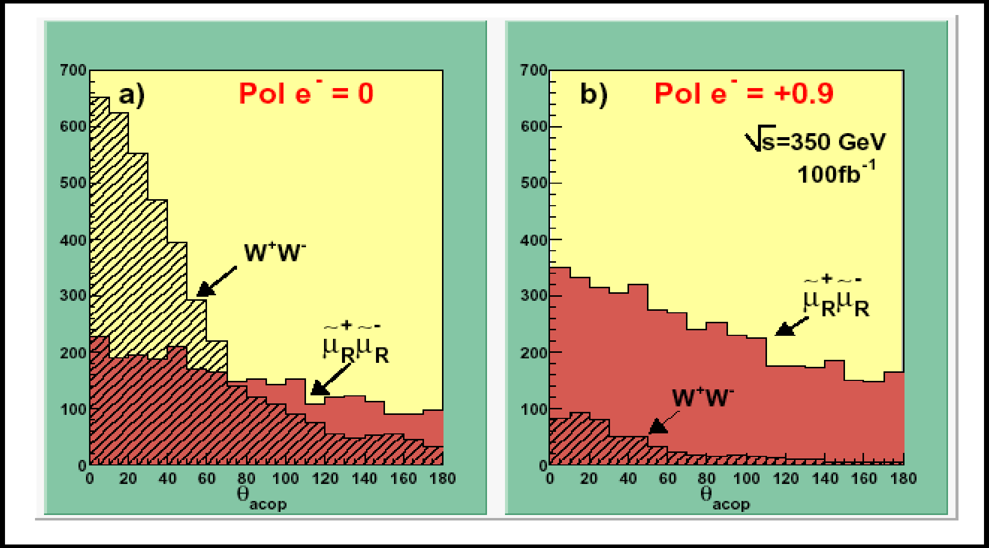
  Increases the H production mode

  $\sigma(\nu\nu H)$ by X 2.34 (=1.8 x1.3)

Background rejection

- Right-handed e- turns off W

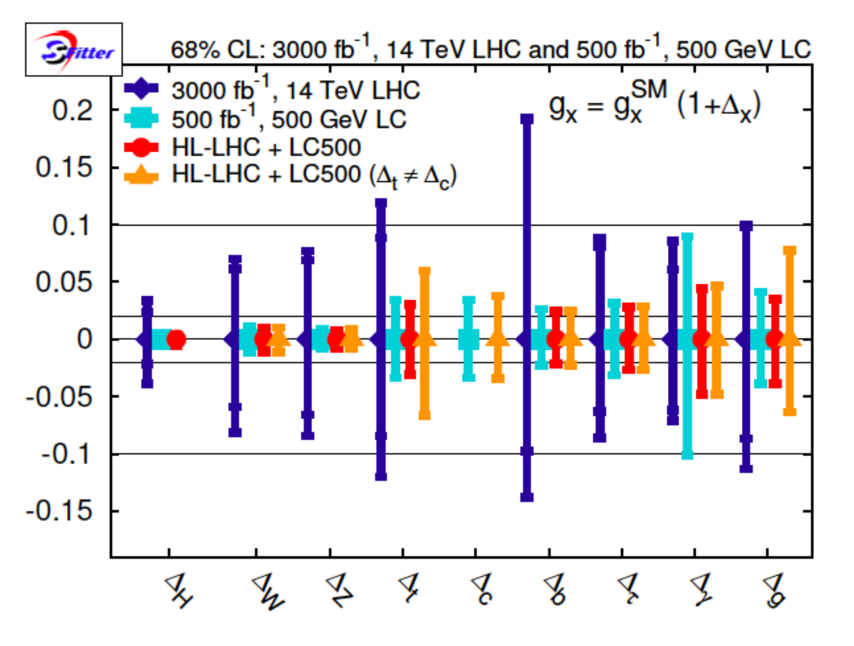




e.g. acoplanar muon pair produciton such as smuon pair production

Measurement errors of Higgs couplings

LHC 14 TeV 3000 fb-1 and ILC 500 GeV 500 fb-1



Klute et al
arXiv:1301/1322v2

500 fb^{-1} of ILC@500 GeV
1.8 E34/cm^{2}s : ~3 years
(1 yr = 1E7 s)

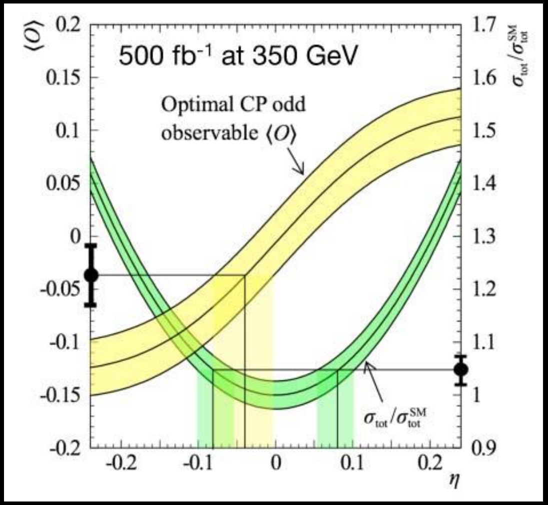
Apart from γ, ILC errors are 1/3~1/10 of LHC
(statistical equivalent: 1~2 orders of magnitude more- at about the same cost)

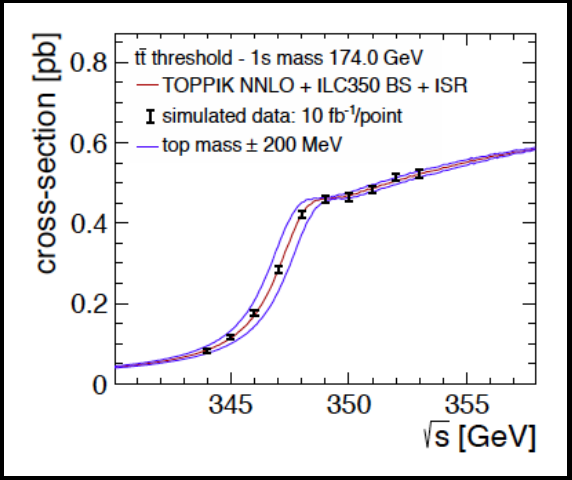
- LHC may improve systematics (both theoretical and experimental)
- ILC by full simulation with bkgs. May improve analysis methods

Great prospect for HEP : ILC and LHC running in parallel!

ILC 250~500 GeV

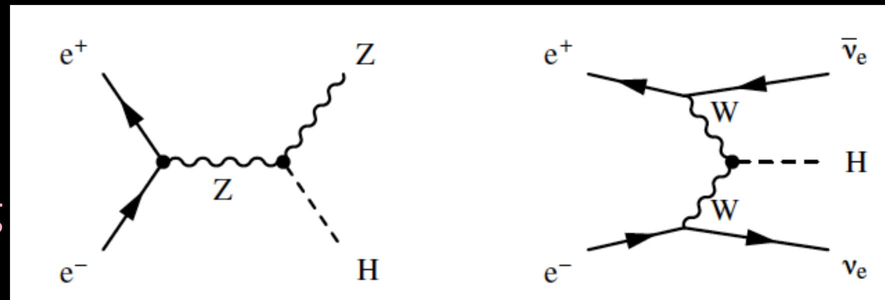
- Higgs
  - Generate ~30K Higgs every year (w/ pol)
    - 5 σ Higgs discovery sensitivity in ~ 1 day
  - Higgs Brs : see previous slide
    - H → cc, invisible (LHC: difficult)
  - Γ_{tot} to 5%
    - Br(H → WW) & g(HWW) by e+e- → ννH
    - Br(H → ZZ) & g(HZZ) by e+e- → HZ
  - CP to 3~4% (on mixing coeff)
- top
  - m_t(msbar) to 100 MeV
  - Anomalous ttZ, tbW, ttg coupl
- New physics through SM
  - Composite Higgs scale to 45 TeV
  - Anomalous WWV coupl
- New unexpected particles!





ILC @1 TeV

Higgsstrahlung



W fusion

	250 GeV	350 GeV	500 GeV	1 TeV
$\sigma(e^+e^- \to ZH)$	240 fb	129 fb	57 fb	13 fb
$\sigma(e^+e^- \to H\nu_e\bar{\nu}_e)$	8 fb	30 fb	75 fb	210 fb
Int. $\mathcal{L}$	250 fb^{-1}	350 fb^{-1}	500 fb^{-1}	1000 fb^{-1}
# ZH events	60,000	45,500	28,500	13,000
# $H\nu_e\bar{\nu}_e$ events	2,000	10,500	37,500	210,000

Luminosity
each energy for ~3 years

- At higher Ecm
  - W fusion dominant
  - More Higgs
  - New particles !

- Good for Higgs self coupling

  e+e- → ννHH
  - Effect of irreducible diagram less important

  $\delta\lambda/\lambda = 0.76\ \delta\sigma/\sigma$ @ 1 TeV

  ($\delta\lambda/\lambda = 1.66\ \delta\sigma/\sigma$ @500 GeV)

  □ $\delta\lambda/\lambda = 17\%$ (2 ab^{-1} @ 1 TeV)

ILC Upgrade Options

- 250 GeV CM (Higgs factory)
  - X4 luminosity @ 3E34/cm^{2}s
  - 120 → 200 MW wall plug
- 500 GeV CM
  - x2 luminosity @3.6E34/cm^{2}s
  - 160 → 200 MW wall plug
- 1.5 TeV CM
  - 6E34/cm^{2}s
  - 340 MW wall plug

Recall the additional x ~2 by polarizations for Ecm > ~1 TeV

ILC Detectors

ILC Detector Performances

- Vertexing $(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$
  - ~1/5 $r_{beampipe}$,1/50~1/1000 pixel size, ~1/10 resolution (wrt LHC)

$$\sigma_{IP} = 5 \oplus \frac{10}{p \sin^{3/2}\theta} (\mu m)$$

- Tracking $(e^+e^- \to Zh \to \ell^+\ell^- X; \quad \text{incl.}\, h \to \text{nothing})$
  - ~1/6 material, ~1/10 resolution (wrt LHC)

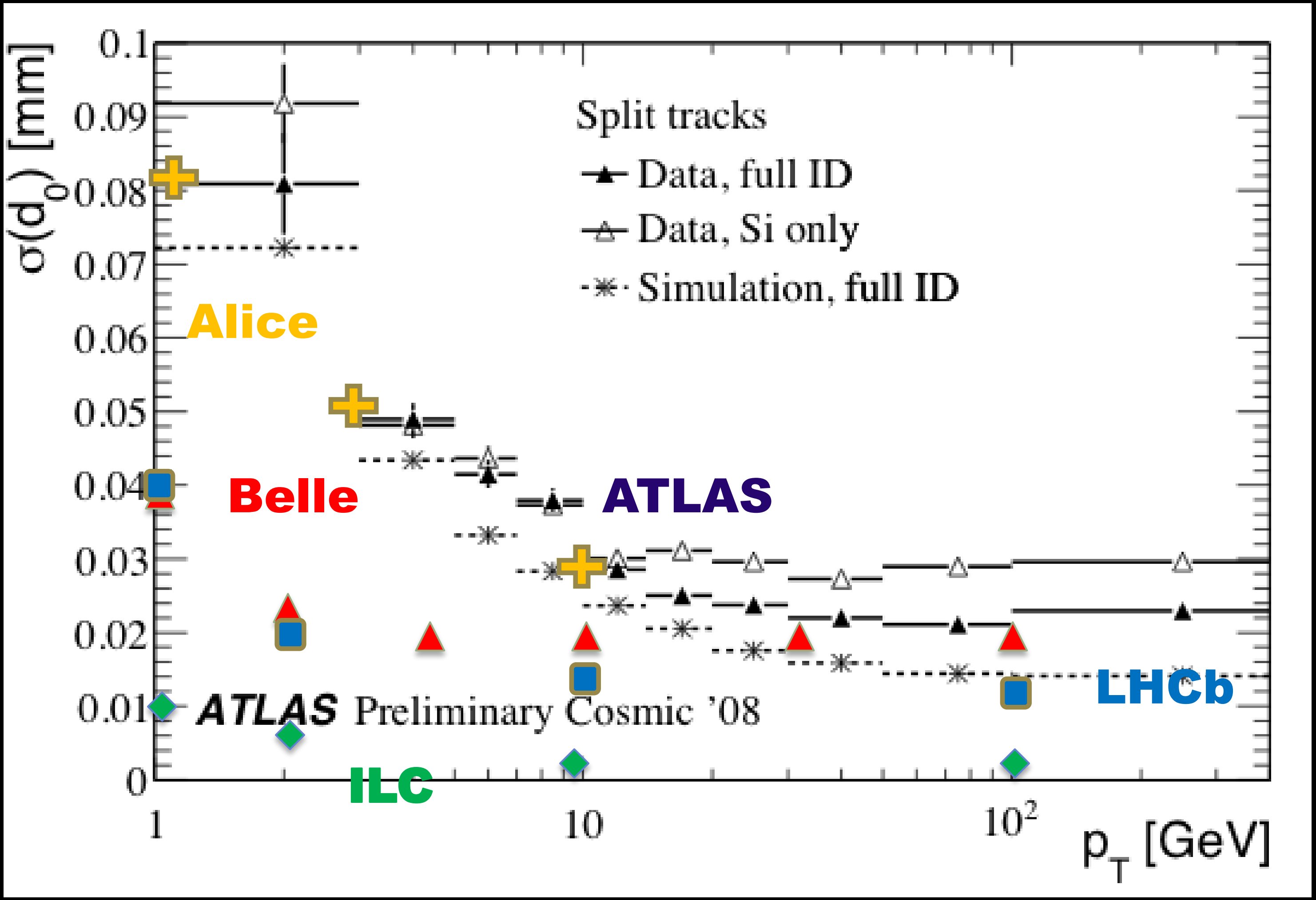
$$\sigma(1/p) = 2 \times 10^{-5} (\text{GeV}^{-1})$$

- Jet energy (quark reconstruction)
  - 1000x granularity, ~1/2 resolution (wrt LHC)

$$\sigma_E / E = 0.3 / \sqrt{E(\text{GeV})}$$

Above performances achieved in realistic simulations based on actual detector R&Ds.

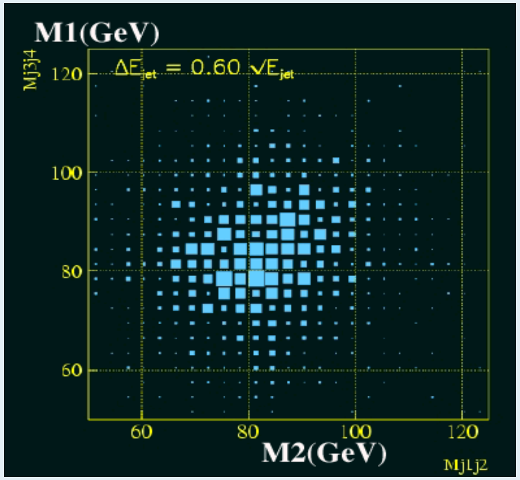
Impact parameter resolution



Jet(quark) reconstruction

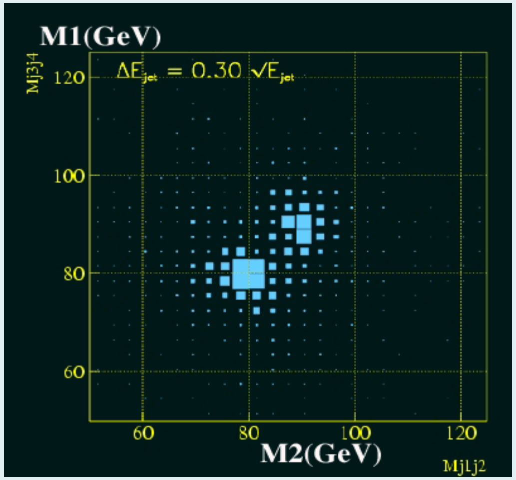
$$e^+e^- \to \nu\bar{\nu}WW, \nu\bar{\nu}ZZ \quad W/Z \to jj$$

Current



$$\sigma_E/E = 0.6/\sqrt{E(\mathrm{GeV})}$$

ILC

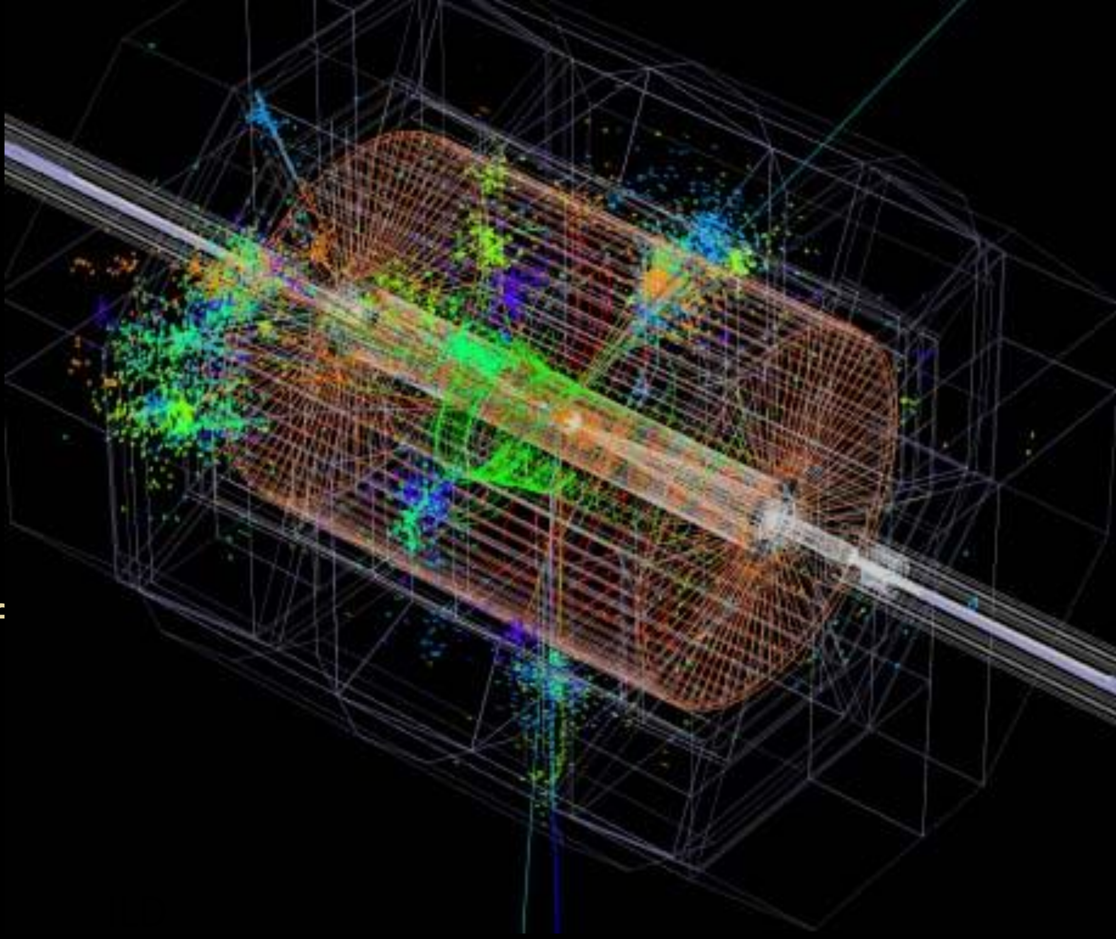


$$\sigma_E/E = 0.3/\sqrt{E(\mathrm{GeV})}$$

- $\sigma_E/E = 0.3/\sqrt{E}$ separates Z/W→jj
- The adopted technique : PFA (particle flow algorithm)

PFA

- Charged particles
  - Use trackers
- Neutral particles
  - Use calorimeters
- Remove double-couting of charged showers
  - Requires high granularity



#ch	ECAL	HCAL
ILC (ILD)	100M	10M
LHC	76K(CMS)	10K(ATLAS)

X10^3 for ILC
Need new technologies !

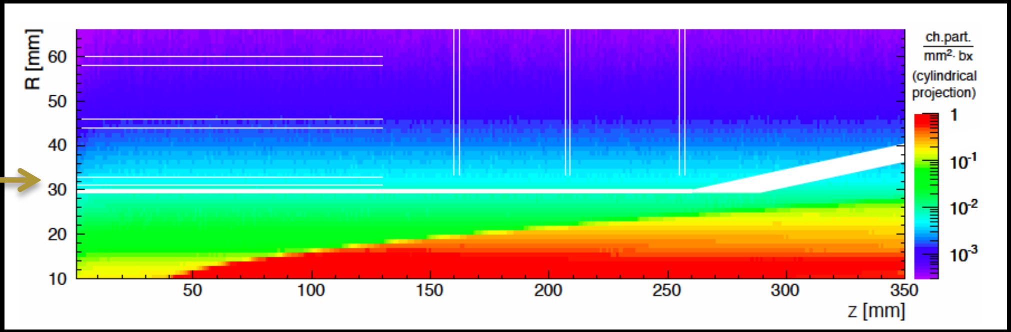
General Considerations (1)

- Calorimeters inside solenoid
  - For good jet reconstruction
- Low mass for tracking&vertexing
  - Thinned silicon sensors
    - e.g. ~50 μm for pixel vertex detectors
  - Light support structures
    - e.g. advanced endplate for TPC
- High granularity esp. for calorimeters&vertexing
  - Fine-granularity calorimeter readout
    - Silicon pad, SiPM, RPC, GEM etc.
  - State-of-the-art pixel technologies for vertexing
    - CMOS, FPCCD, DEPFET, SOI, 3D…
  - Front-end electronics embedded in/near the active area (cabling!)

General Considerations (2)

- As hermetic as possible
- Vertex detector as close as possible to beam
  - Limit: e+e- pair background

Beam pipe

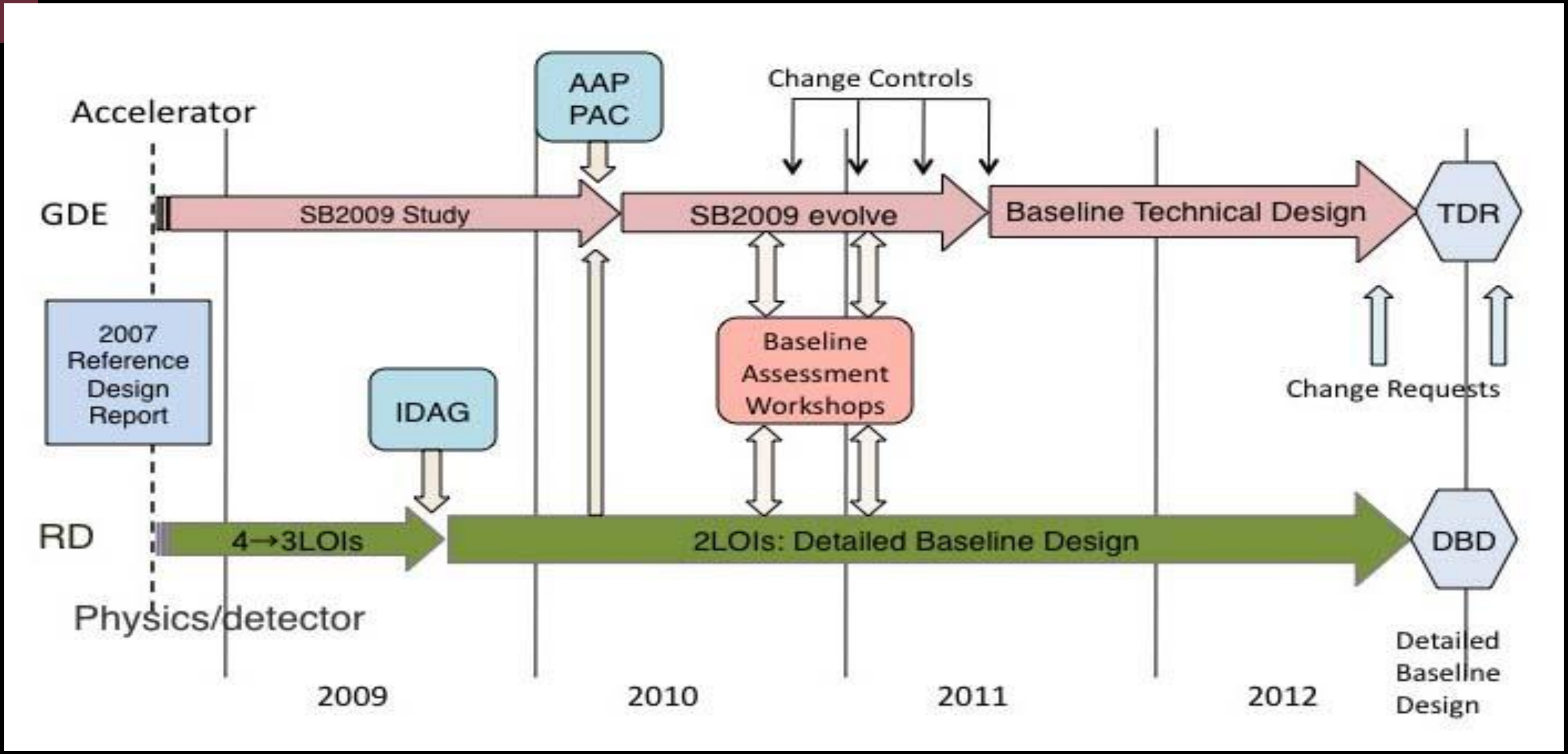


Density of pairs near IP
High B field helps
Worse for high E_{CM}

- Low heat generation (cooling eats up material budget)
  - Low-power front-end electronics
  - Power pulsing
    - Turn off power during bunch train gap

	#bunch/train	train length	train gap	duty factor
ILC	1312	727μs	200ms	0.36%

ILC recent history

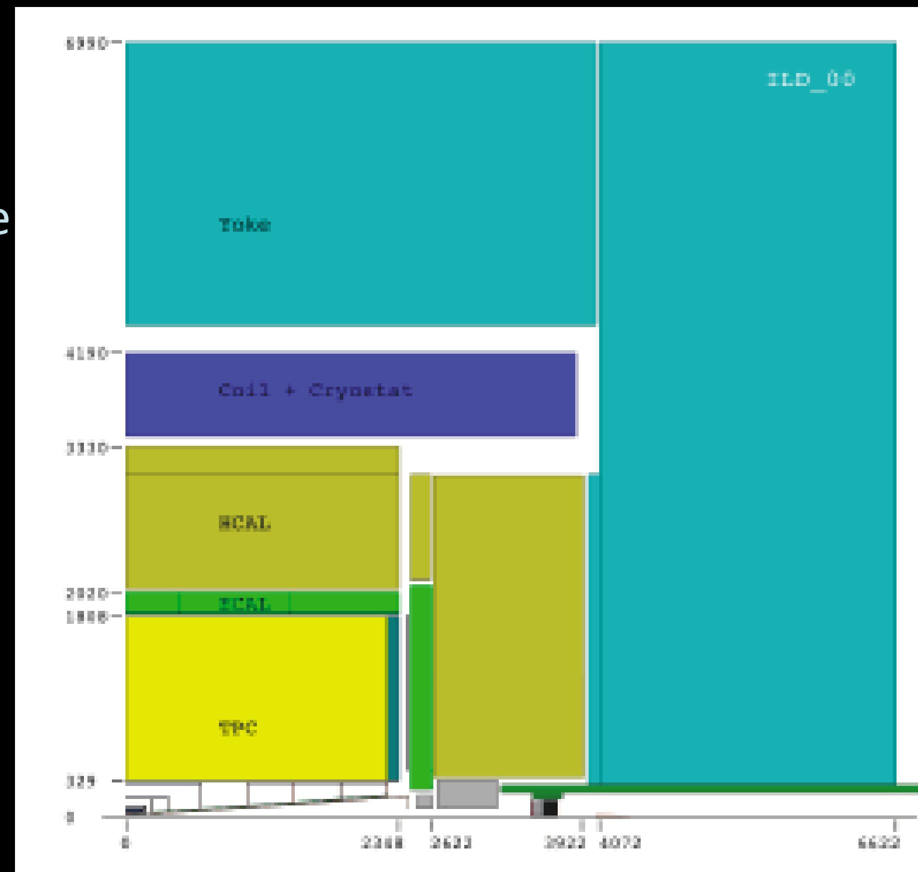


- IDAG (International Detector Advisory Group):
  - Validated two detectors: ILD and SiD in 2009 summer
- ILD and SiD:
  - completed DBD (Detailed Baseline Design) (June, 2013)
- New organization LCC (Linear Collider Collaboration) took over
  - Feb – June , 2013 : transition period

ILD

- B: 3.5 T
- Vertex pixel detectors
  - 6 (3 pairs) or 5 layers (no disks)
  - Technology open
- Si-strip trackers
  - 2 barrel + 7 forward disks (2 of the disks are pixel)
  - Outer and endcap of TPC
- TPC
  - GEM or MicroMEGAS for amplification
  - Pad (or si-pixel) readout
- ECAL
  - Si-W or Scint-W (or hybrid)
- HCAL
  - Scint-tile or Digital-HCAL

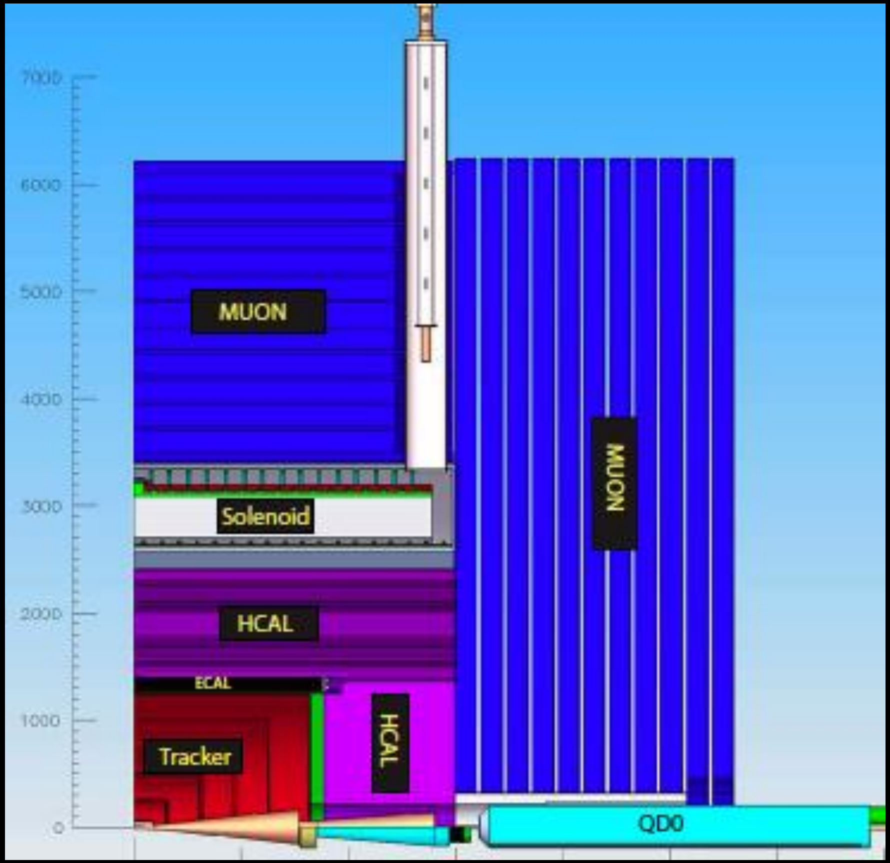
All above inside solenoid



SiD

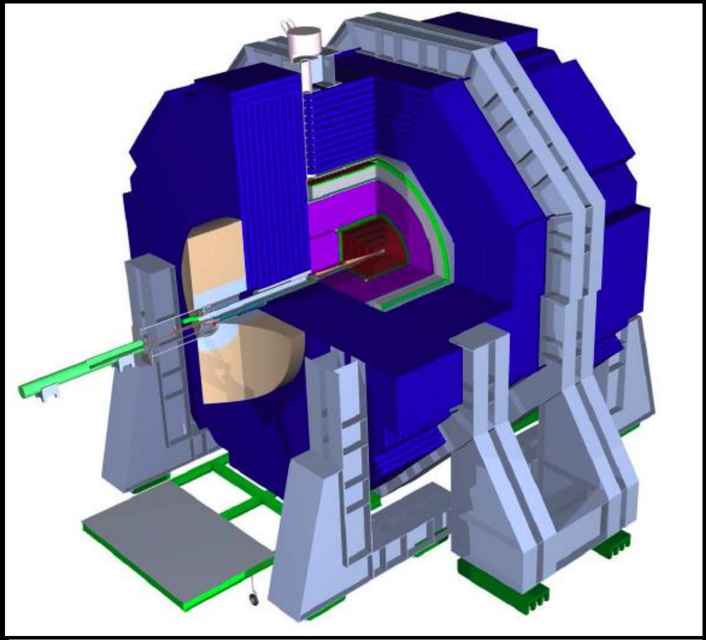
- B: 5T
- Vertex pixel detectors
  - 5 barrel lyrs +
    (4 disks+3 fwd)/side
  - Technology open (3D)
- Si-strip-trackers
  - 5 barrel lyrs + 4 forward disks/side
- EMCAL
  - Si-W 30 lyrs, pixel ~$(4mm)^2$
- HCAL
  - Digital HCAL with RPC or GEM with $(1cm)^2$ cell
  - 40 lyrs

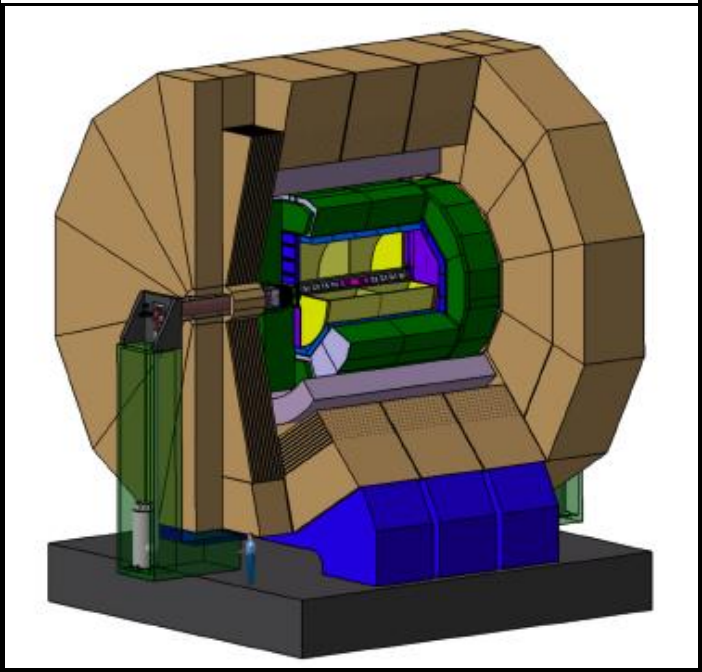
All above inside solenoid



Design Strategies

- SiD
  - High B field (5 Tesla)
  - Small ECAL ID
  - Small calorimeter volume
    - Finer ECAL granularity
  - Silicon main tracker
- ILD
  - Medium B field (3.5 Tesla)
  - Large ECAL ID
    - Particle separation for PFA
  - Redundancy in tracking
  - TPC for main tracker

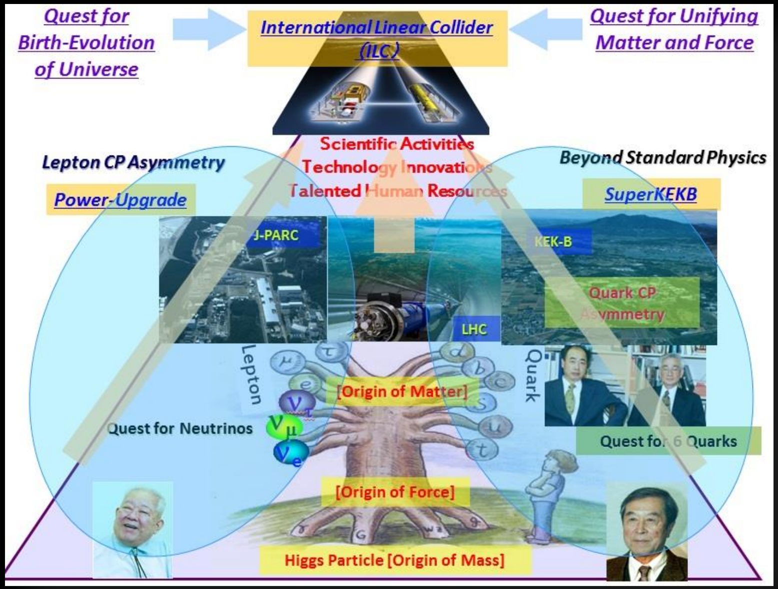




Situation in Japan

KEK roadmaps

- 2007
  - ILC at the top of the pyramid



- 2013
  - KEK will play a central role in creating an international preparatory group and will lead the effort on advanced R&D, the engineering design of the apparatus and facility, and the organizational design toward groundbreaking for the linear collider project to be hosted in Japan, within the framework of a global collaboration.

JAHEP (Japan Association of High Energy Physicists)

- A report on large projects (March 2012)
  - On ILC:

    Should a new particle such as a Higgs boson with a mass below approximately 1~TeV be confirmed at LHC, Japan should take the leadership role in an early realization of an e+e- linear collider. In particular, if the particle is light, experiments at low collision energy should be started at the earliest possible time.

  (Now, Higgs particle has been found and it is ‘light’)

- A proposal for staging of ILC (October 2012)
  - Staging
    - A Higgs factory with a CM energy of ~250 GeV to start
    - Upgraded in stages to ~500 GeV (RDR baseline)
    - Technical expandability to ~1 TeV to be secured
  - Guideline for cost sharing
    - The host country to cover 50% of the expenses (construction) of the overall project of the 500 GeV machine. The actual contributions left to negotiations among the governments.

International Supports

- Europe : 'European Strategy' (March 22, 2013)
  - There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded … The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. Europe looks forward to a proposal from Japan to discuss a possible participation.
- US : HEPAP facilities subpanel report (March 22, 2013)
  - The initiative from the Japanese particle physics community to host the ILC in Japan is very welcome, and the U.S. particle physics community looks forward to a proposal from Japan to discuss possible participation.
  - For the final US strategy, wait for the Snowmass process and the P5 subpanel report.

Political support :

LDP (Liberal Democratic Party : New Ruling Party) election platform

‘ILC’ appears twice explicitly

32 Rebuilding true command tower functions that strongly advance science and technology policies

- …We will actively promote the critical fields of energy creation, energy conservation, energy storage, etc. as knowledge-concentrated national strategies - for example, our country should be able to play a leading role in creation of international centers for scientific innovations such as the ILC (the international linear collider) project which is a grand project in the field of particle physics.

92 Creation of globally top-class centers for research and development

- …We will significantly strengthen supports for universities and public research facilities that perform studies at levels above the intentional standards, such as significant expansion of WPIs and playing a leading role in creation of international centers for scientific innovations such as the ILC (the international linear collider construction) project which is a grand project in the field of particle physics.

Press conference by the MEXT minister Shimomura

Jan 18, 2013

‘(On ILC) We would like to consider the plan for the near future, while as the government actively negotiating with relevant countries in the first half of this year … we are now studying the legal framework.’

Support by Industries:

A report by the Association of Corporate Executives (経済同友会: one of the two such groups in Japan）

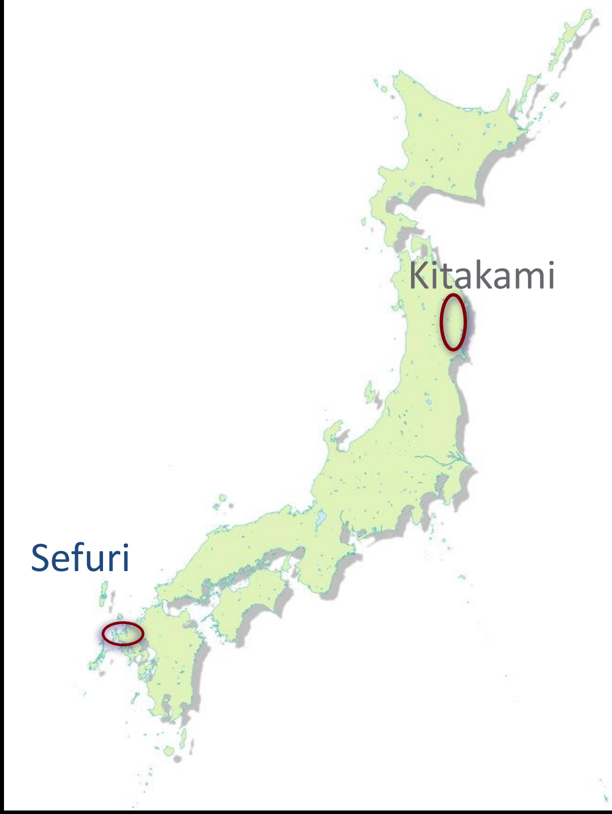
'… The Japanese government should announce the intention to site the ILC in Japan, and propose to related countries to begin discussions toward its realization. '

'… On down-selecting the Japanese candidate sites to one, it is important to proceed with a fair selection process in order to build an All-Japan framework. The selection process should be based on the results of the geological and technical studies being conducted by experts, and should be decided fairly.'

Two Candidate Sites

- Kyushu
  - Sefuri mountains
- Tohoku
  - Kitakami mountains

Strong and stable granite bedrocks



One of them will be chosen by end of July 2013 based on:

- Geology and technical aspects
- Infrastructure and economic ripple effects
- International Review by LCC before the announcement

Times line
(The possible best scenario)

- End 2013
  - Japanese government announces its intention to host the ILC. It will start negotiation with other government.
- 2013-2015
  - Negotiations among governments
  - Finish R&Ds. Prepare for the international lab.
- 2015-2016
  - Bidding for construction, start construction
- 2026-2027
  - Start operation

Summary

- With the discovery of Higgs, the physics case for the ILC is now stronger than ever
- The ILC detectors are pushing the state of the arts of particle detection technologies
- The proof of principles for the ILC detectors are complete
- Japanese government is now willing to negotiate with other governments toward siting the ILC in Japan.
- There are strong supports from the international scientific community. (will they translate to real commitments?)